

# FROM DESTRUCTIVE AGRICULTURE WITH SOIL TILLAGE TO SUSTAINABLE AGRICULTURE WITH DIRECT SEEDING MULCH-BASED SYSTEMS: 20 YEARS OF RESEARCH BY CIRAD AND ITS BRAZILIAN PARTNERS IN THE CERRADOS REGION IN BRAZIL.

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## 1) INTRODUCTION

About 23% of the land in Brazil is covered by the 200 million hectares of the 'Cerrados' ecosystem, of which at least 50 million ha can potentially be used for intensive mechanised agriculture (Embrapa, 1998). A large proportion of this arable land is in the humid tropical zone in the west and north of the region at the edge of the Amazon forest. Some Brazilian agricultural development specialists affirm that the full rational, intensive cultivation of this 'reservoir' of land could produce—without supplemental irrigation—more than 150 million tonnes of grain, 9 million tonnes of meat and more than 300 million m<sup>3</sup> of wood while holding back 20% of the area for environmental conservation reasons (Goedert, 1989). The Cerrados thus form a vast as yet little-exploited reserve available to feed humans in the twenty-first century. It can be used for perennial crops, annual food and industrial crops and also livestock production. However, man must know how to exploit this environment in a sustainable manner and without degrading it.

Cultivation of Cerrados humid tropical savannah started towards the end of the 1970s. Farmers arrived from the southern states and rapidly colonised the central western states and then the more humid west. Mechanised agriculture was developed there after clearing of the land and sowing some cycles with rainfed rice and extensive grazing (*Brachiaria* sp.). It was subsequently centred on industrial growing of soybean as a sole crop to produce exportable surpluses. This farming method used only disc-ploughing and soon turned out to be disastrous with strong precipitation of from 1,500 to more than 2,000 mm distributed over only 7 months, with catastrophic erosion of landscape units (Derpsch *et al.*, 1991) causing initially an insidious decrease and then a rapid continuous fall in soil productivity in spite of the increased use of chemical inputs (inorganic fertiliser, pesticides), leading to spectacular bankruptcies (Séguy *et al.*, 1996).

CIRAD and its partners<sup>1</sup> have operated on the pioneer fronts in the central northern Mato Grosso where more than 1.3 million hectares is cultivated today. The aim was to set the bases for sustainable agriculture in order to settle this and thus reduce the pressure on the hitherto uncolonised zones. Operations were first in the savannah area from 1983 to 1994 and then in the forest zone as well to precede and prepare for the possible arrival of mechanised pioneer fronts in an environment to be protected absolutely. As the economic context was very unstable and the fragile physical environment is subjected to excessive climatic constraints, the sustainable management of soil resources at the least cost was the major research objective and that was not dissociable from the economic risk evaluation. Starting from widespread soybean monoculture that was disastrous for the physical environment, this management of the economic risk resulted in the gradual development of diversified direct seeding mulch-based (DMC) cropping systems. This pioneer research work enabled very substantial, rapid

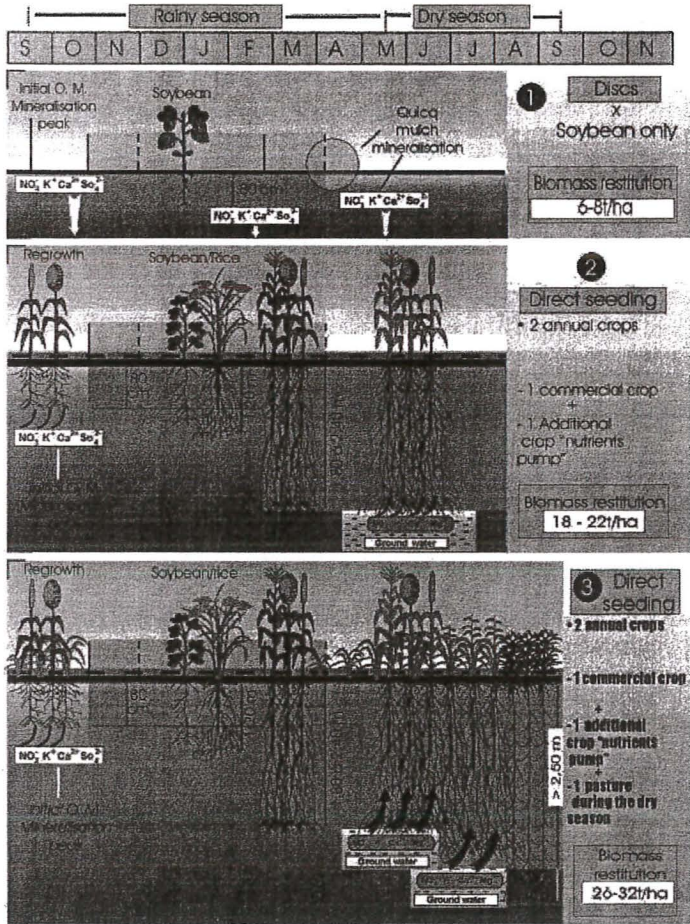
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<sup>1</sup> The team consisting of L. Séguy, S. Bouzinac and their Brazilian research and development partners, with permanent co-operation with farmers (including the pioneer, Mr Munejume Matsubara), the CNAF (Embrapa Rice & Beans), EMPAER-MT, the Mato Grosso state research centre from 1986 to 1989, and then partnership with RHODIA (a Brazilian subsidiary of Rhône Poulenc) and the COOPERLUCAS co-operative in Lucas do Rio Verde from 1990 to 1995, and more recently with the Prefecture of SINOP, the MAEDA group, COODETEC and the AGRONORTE private research enterprise from 1995 to 2002

expansion of direct seeding in the Cerrados<sup>2</sup> from the early 1990s onwards, with more than 5 million hectares concerned in 10 years (Source: FBPDP, 2001; www.fbrapdp.org.br).

**II) DIVERSIFIED DIRECT SEEDING MULCH-BASED SYSTEMS (DMC) WITH INCREASINGLY GOOD PERFORMANCE**

*The characteristics and general principles of DMC in the humid tropics*



SOURCE: L. Seguy, S. Bouzinac, CIRAD-CA; A. Maroniezzi, Agronorte - Sinop/MT - 2001

**Figure 1 : Cropping systems in the Cerrados Region, DMC systems improvements in biomass production and resources valorization**

<sup>2</sup> Thanks also to the work of John Landers and partner farmers in southern Goiás in the early 1980s and, more recently, to the dissemination work carried out by APDC (Association for direct seeding in the Cerrados) and the regional CATs (Club des Amis de la Terre)

The new DMC systems developed by the research sector should meet the following criteria: they must be justified and reproducible in an agronomical point of view, technically practicable with conservation of soil fertility, make the most of the strong available water potential, be economically profitable and more stable than the systems currently used. In parallel with the sustainable management of the soil potential, the quest for diversification and quality produce in rotations has also been considered as a priority to achieve maximum value-added. Varietal improvement programmes have therefore been set up in these cropping systems and especially for high-technology rainfed rice and for cotton. Various cropping systems were developed successively in the humid tropical zone from 1986 to 2002, starting from the destructive soybean monoculture system with tillage that produced small and fugacious annual quantities of biomass:

- systems with a single annual crop based on the soybean-grain (rice, maize) rotation with tillage (introduction of the rotation),
- then systems alternating two annual crops in succession with direct seeding in one year and a single crop the subsequent year,
- then systems with two annual crops in succession with continuous direct seeding with the second crop referred to as the '*safrinha*' playing the role of 'nutrient pump' (Séguy *et al.*, 2003),
- and finally systems with three crops per year, all with continuous direct seeding, consisting of one commercial crop (soybean, rice, maize) followed by 'nutrient pump' cereals (maize, millet, sorghum, *Eleusine*) as '*safrinha*' intercropped with forage species that are also powerful 'nutrient pumps' and produce large amounts of biomass in the dry season and can be used as green manure or grazed (the genera *Brachiarias*, *Stylosanthes* and *Cajanus*, single-cropped or combined) (Séguy *et al.*, 2001a, 2001b).

In these last DMC systems, as in forest ecosystems, the combination 'commercial cereal crop + forage species' following—at the end of the rainy season—the first commercial crop, uses water substantially deeper than 2 m during the dry season. The combination also displays very strong vegetative regrowth after the first rains in the following season or after dry season rain, thus ensuring the complete, permanent covering of the soil [Fig.1].

Total annual dry matter production (above and below soil) increased from 4 to 8 t/ha in 1986 in the initial systems with a single annual crop to an average of over 30 tonnes/ha in 2000 in the best DMC systems.

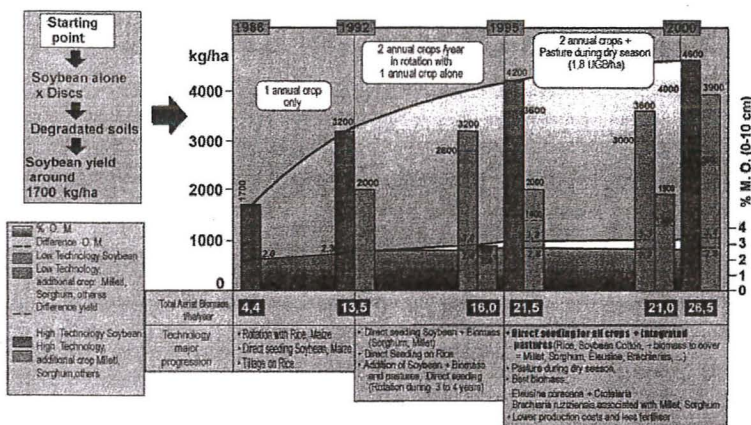
#### ***The impacts of these DMC systems on production*** (Séguy *et al.*, 2001a; 2002)

Soybean is the main crop in the central northern region of the Mato Grosso and its productivity increased with the gradual improvement of DMC systems from 1,700-2,000 kg/ha in 1986 to more than 4,500 kg/ha under experimental conditions from 2000 onwards [Fig.2].

In the past five years, DMC systems has become increasingly well managed (accumulation of knowledge, refining of practices and varieties). The results of the research conducted by CIRAD show that soybean yields are closely correlated with the quantity and quality of the Gramineous plants that serve as dead or live cover (mulch: maize, sorghum and millet grown with *Brachiaria ruziencis* and *Eleusine coracana*; live cover: *Cynodon dactylon*).

With very small application of inorganic fertiliser (40 kg P<sub>2</sub>O<sub>5</sub> + 40 kg de K<sub>2</sub>O per ha), showing the soil organo-biological production capacity, soybean productivity increased each year in the best DMC systems, whatever the cycle of the variety used, in comparison with the 'monoculture x disking' system. Differences were from 12-15% in the first year to 45-52% in the fifth year. The average annual increase in yield under DMC was more than 700 kg per ha over a 5-year period.

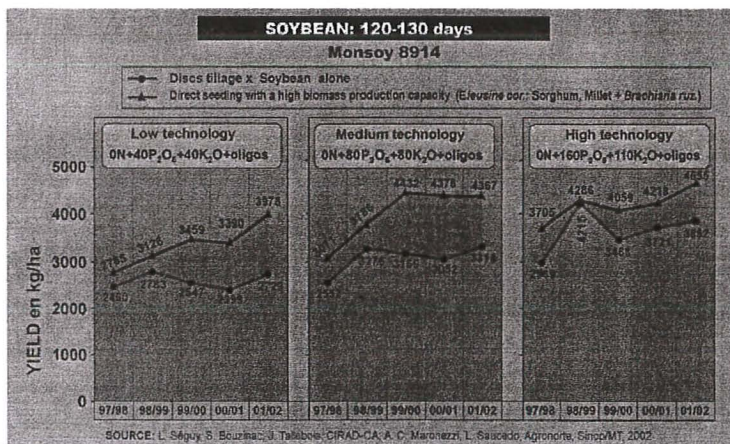




SOURCE: L. Seguy, S. Bouzinac, CIRAD-CA; M. Matsubara, Foz. Progresso; A. Trentini, Cooperlucas; A. C. Maronezzi, Agronorte - MT, 1998/2000

**Figure 2 : Evolution of soybean yields under DMC systems with successive improvements between 1986 and 2000 in the Cerrados region.**

With this very low level of fertilisation, soybean productivity in the best DMC systems ranged from 3,100 kg/ha in short cycles to over 3,500 kg/ha in intermediate cycles from the third year onwards. Whatever the soybean cycle, the average yield over 5 years is higher in the best DMC systems with little fertilisation (40 kg  $P_2O_5$  + 40 kg  $K_2O$  per ha) than in the 'monoculture x disking' system with double the fertilisation and close to that achieved in the same system with non-limiting fertilisation (160 kg  $P_2O_5$  + 110 kg de  $K_2O$  per ha) [Fig.3].



SOURCE: L. Séguy, S. Bouzinac, J. Tallibon, CIRAD-CA, A. C. Maronezzi, L. Saucedo, Agronorte, Sinop/MT, 2002

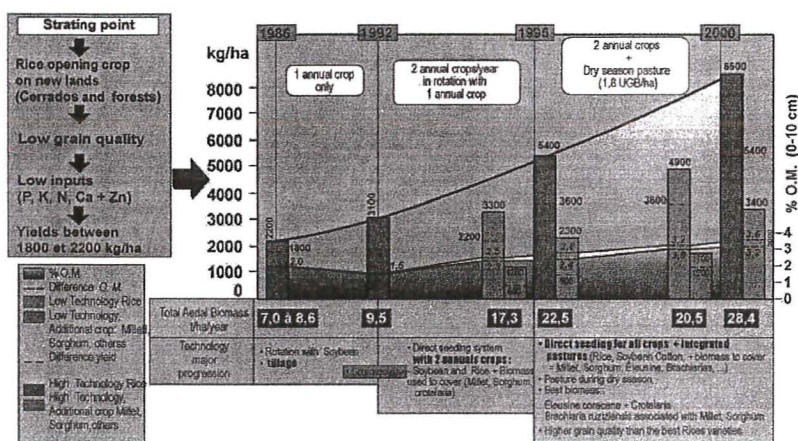
**Figure 3 : Five years evolution of an intermediate soybean yields in function of the cropping systems in Sinop (MT), 1997-2002.**

With medium fertiliser application (80 kg  $P_2O_5$  + 80 kg  $K_2O$ /ha), the most common practice in the region, high-potential intermediate cycle soybean cultivars display increased productivity in the best DMC systems, producing over a 5-year period 16 to 40% more than the monoculture systems. Their

yields exceed 4,300 kg per ha from the third year of DMC cultivation. The short cycle varieties have lower potential and a smaller annual gain in yield with DMC of 516 kg per ha in comparison with 934 kg per ha for the intermediate cycle cultivars.

These results prove the increase in soil production by the organo-biological pathway under DMC. More is produced with much less inorganic fertiliser. This leads to considering that the best cultivars should be chosen for and in the best DMC systems. Indeed, this optimises the genotype-environment interactions as the environment is very strongly modified by farmers' soil management procedures.

The potential productivity of rainfed rice observed in controlled trials in the region increased from 1,800-2,000 kg per ha in 1986 to more than 8,000 kg per ha in 2000 (with a record of 8,500 kg ha in large-scale cropping at Campo Novo dos Parecis in 1998/99). This has been accompanied by an important improvement in grain quality which is now as good, and sometimes better, than that of the best irrigated varieties (Séguy *et al.*, 1998b) [Fig.4].



SOURCE: L. Seguy, S. Bouzinac, CIRAD-CA; M. Matsubara, Faz. Progresso; A. Trenfili, Cooperlucas; A. C. Maronezzi, Agronorte - MT, 1988/2000

Figure 4 : Evolution of rainfed rice under DMC systems with successive improvements between 1986 and 2000 in the Cerrados region.

As for soybean cultivation, gains in yields by the best DMC systems over a 5-year period range from 23% to more than 43%. Rice productivity is also closely correlated with the quantity and quality of the biomass produced by combinations of Graminious plants with the most powerful restructuring root systems (*Eleusine coracana*; maize, sorghum or millet intercropped with *Brachiaria ruziziensis*) and deep-rooting, nitrogen-fixing legumes (*Crotalaria* sp., *Cajanus cajan*, *Stylosanthes guyanensis*).

The creation of rainfed rice varieties and hybrids is performed for and in the best DMC systems<sup>3</sup>. This germplasm is strongly diversified from the commercial point of view (long to very long, perfumed rice with varied amylose contents) and displays a production potential of some 9,000 kg per ha in rainfed DMC systems and much more than 10,000 kg per ha with irrigation. Their rainfed features, with resistance to water shortage and their stable resistance to diseases make them excellent for use in rainfed DMC systems in the humid tropics, under sprinkler irrigation in areas with little or no rainfall and in lowland areas and rice perimeters with poor control of water when the facilities are degraded.

<sup>3</sup> In co-operation with the private research undertaking **AGRONORTE** based in Sinop since 1998. **CIRAD** has been one of the pioneers in rainfed rice with high potential and high grain quality in the central western region of the Mato Grosso: the IRAT 216 variety was grown on 20,000 ha in 1991; this was followed by the cultivar Progresso and then CIRAD 141 grown on 300,000 ha in 1998/99 and finally Sucupira on several tens of thousands of ha from 2001/02 onwards.



Cotton<sup>4</sup> is the new major DMC crop in the humid tropical Cerrados. The Mato Grosso became Brazil's leading supplier<sup>5</sup> over a period of three years (1998-2001) with total fibre production of more than 300,000 tonnes in 2001.

The research conducted by CIRAD and its partners in the Mato Grosso has benefited from preceding work developed in less rainy regions (1000-1600 mm per year) in the south of Goiás state and the north of São Paulo state from 1994 to 1999, establishing the rules for the management of direct seeded cotton growing (Séguy *et al.*, 1998a; Séguy *et al.*, 2001b).

This shows that cotton growing with large amounts of chemical inputs is not sustainable with present practices, even when cover crops are used and tillage is reduced. It is certainly very productive initially with 3,000 to 4,500 kg/ha seed cotton, on land improved by 5 to 10 years of continuous direct seeding (sequences of soybean + maize or millet). However, productivity then tends to decrease under the negative influence of soil degradation and excessive monoculture. This situation is often justified by producers by high investment and the necessary return to the use of disc ploughs, and hence tillage, to plough in large amounts of calcium-magnesium amendment and to destroy cotton regrowth after the harvest. This prophylactic measure is required by law for the control of the pests *Anthonomus grandis*, *Pectinophora gossypiella*, *Aphis gossypii* and ramulosis (*Colletotrichum g.*). The land is often finely tilled a second time in the same year when the cover biomass (millet, sorghum) is sown prior to the direct seeding of cotton. This system is similar to the conservation tillage used in Europe and is referred to locally as 'semi-direct seeding'. It exposes the soil to erosion again, accelerates the mineralisation of organic matter (whose annual balance becomes negative) and brings buried weed seed to the surface competing with cotton.

The most recent research results on optimised soil and crop management under DMC show that cotton productivity can be sustainable if true direct seeding is performed (chemical control of regrowth, direct seeding of cover biomass and no tillage) and the cotton is maintained in the framework of diversified rotations that contribute large amounts of biomass (both above and below ground). Cotton growing is thus performed one year in two or three (annual sequences of soybean + maize or millet combined with *Brachiaria ruziziensis*; soybean + *Eleusine coracana*).

This diversified DMC management makes it possible to use smaller amounts of chemical inputs (amendment, fertiliser, pesticide) and to maintain high seed cotton yields of between 3,500 and 5,000 kg/ha.

The choice of cultivar should be performed according to the biological quality of the soil, with hardy cultivars (such as IAC 24) for a strong negative biological pressure (as in monoculture) and more sophisticated, high potential cultivars with better fibre quality for diversified DMC systems (FIBERMAX 966, COODETEC 406 and 407) (Séguy *et al.*, 2002).

The total productivity of cropping systems has been considerably improved thanks also to the production of crops in the annual sequence (second annual cycle) such as maize, millet, sorghum and *Eleusine* that yield 2,000 to 4,000 kg per ha, and cotton with yields of 2,250 to more than 3,000 kg per ha seed cotton. These 'safrinhas' crops are conducted with a minimum of inputs or with no inputs at all and may be followed by cattle fattening during the dry season when forage species are intercropped (this is the case of maize, sorghum and millet intercropped with grasses forage). With the exception of cotton, although the commercial value of these crops is still very under-exploited in the region, they can still be used as feed for livestock (cattle and pigs) in the dry season and be used profitably in meat or milk production. After 15 years of research, the best DMC systems can thus now produce the following amounts in one year: 4,500 kg/ha of soybean or more than 6,000 kg/ha of rice followed by 1,500 to 3,000 kg/ha of maize, sorghum, millet or *Eleusine coracana* and 65 to 90 kg/ha of meat in the dry season, or 3,000 to 4,500 kg/ha of cotton in rotation with the preceding grain + pasture systems (Séguy *et al.*, 2001a; 2001c).

<sup>4</sup> CIRAD and the MAEDA group were the precursors in the direct seeding of cotton from 1994/95 under the ecological conditions of the tropical forests in the south of Goiás state and the north of São Paulo state on rich ferrallitic soils derived from basalt (L. Séguy *et al.* 1998, 2000)

<sup>5</sup> Thanks to the combined efforts of UNICOTTON, COODETEC, FUNDAÇÃO MT, MDM, EMBRAPA, MAEDA and CIRAD (in partnership with MAEDA and COODETEC)

These high annual biomass production figures were also obtained thanks to the 'multifunctional' character of some of the plants used in the rotations (Séguy *et al.*, 2003), further increasing the overall efficiency of the system. For example, as DMC systems function on a closed-system basis like the forest ecosystem, with no noteworthy loss of nutrients and with effective neutralisation of the harmful effects of aluminium toxicity on sensitive crops (soybean, maize and cotton), they make it possible to save a considerable proportion of calcium-magnesium ameliorators (e.g. the annual sequence of soybean + maize intercropped with *Brachiaria ruziziensis* reported by Séguy *et al.*, 2000). Pest pressure (bacterial wilt and fungal diseases, nematodes and pests) decreases very significantly in diversified DMC systems (rainfed rice, cotton and soybean) and the sanitary state of the crops is considerably improved (Séguy *et al.*, 1998c). Fungi of the genus *Nomurea* and the virus *Anticarsia* develop with DMC systems and are valuable agents for the biological control of leaf-eating caterpillars. Dung-beetles, termites, ants and worms contribute to maintaining high macroporosity (Assad, 1997). Guinea sorghum cover perfectly controls the weed *Cyperus rotundus* on ferrallitic soils on basalt and also effectively cleanses the same soils when they are polluted by sulfentrazone (phytoremediation) (Séguy *et al.*, 1999 and 2001a). The judicious choice of cover biomass in DMC systems now makes it possible, after the mechanical or chemical desiccation of the biomass preceding direct seeding, to considerably reduce or entirely eliminate other herbicides on crops. This agronomic pathway for natural weed control by the choice of cover plant could form an interesting alternative to GMOs that is less of a constraint for producers.

This spectacular progress has been achieved on soils that are chemically particularly poor in a particularly aggressive climate thanks to the simultaneous optimisation of soil management and the management of germplasm resources selected for and in DMC systems.

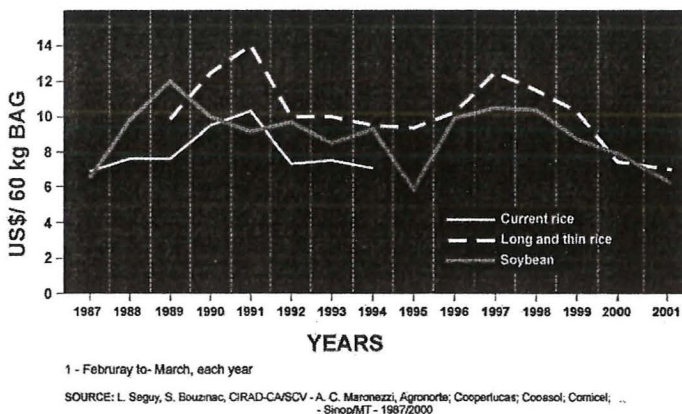
#### *Economic consequences: 'king soybean', rice for the poor and delicate cotton*

The economic situation in the pioneer front region in the central northern Mato Grosso has been very unstable since the beginning in the early 1980s. It was hit directly by the country's various economic restructuring operations. The region is far from the major processing centres and export ports (more than 1500 km) and has only one road, generally in precarious condition, increasing transport costs. This isolation results in economic penalisation with 25 to 40% extra production costs in comparison with the major production states in southern Brazil (Séguy *et al.*, 1996).

In this very unstable situation and in spite of strongly fluctuating prices [Fig. 5], soybean has always benefited from the security of a sector with solid organisation for export. The crop is now a leader and paid for in dollars, the most reliable and hence the most planted (more than 1.3 million ha in the central northern Mato Grosso, APDC, 2003). Total production costs in the best DMC systems range from \$US 260 to 325 per ha and the margins are between \$US 90 and 200 per ha according to the degree of intensification (Séguy *et al.*, 2001a; 2001b).

In spite of the exceptional improvement of yields and quality, rainfed rice is still the staple foodstuff of the poorest people in Brazil and so the various governments keep the price very low. As rice is one of the components of the 'shopping basket', it is a commodity with political significance. It is the poor relation in the cropping systems and its price, which can double, is never guaranteed [Fig.5]. Furthermore, the quality of the grain is not yet rewarded by the market. This permanent uncertainty continues to restrict the crop to newly cleared land where productivity is naturally very high (from 4,200 to more than 6,000 kg per ha) with minimum inputs. Nevertheless, in the DMC systems with the best performance and that are now well managed, high quality rainfed rice is a reliable feature for diversification on previously cleared land in the humid tropical zone. It is comparable to wheat in temperate regions. Total production costs and net margins are close to those of soybean in the best DMC systems.





**Figure 5 : Prices paid to the farmers for rice and soybean productions at Sinop (MT) in the Cerrados region between 1987 and 2000**

The profitability and sustainability of cotton in the present 'semi-direct seeding' system are not assured. Profitability is high but stagnant at best and sometimes decreases. Production costs are very high (\$US 1,000 to 1,100 per ha; these have now become greater than the cost of the land) and rising because of the increasing use of pesticides. This economic risk is accentuated by the strong fluctuations of world fibre prices. The results obtained by CIRAD and its partners shows that the crop can still be profitable in an unfavourable economic situation and make further progress on condition that it is part of a rotation and grown one year in two or one year in three in diversified DMC systems with no tillage, which alone guarantees lower production costs. The costs resulting from mechanisation have been reduced drastically by the adoption of direct seeding. The pool of tractors and seeders can be reduced by half, as can fuel consumption (Séguy *et al.*, 1998a).

These economic constraints account for the exponential adoption of direct seeding from 1995 onwards in a region where, to survive, farming without subsidies has to produce more and as cheaply as possible. Today, more than 80% of the area is under DMC but with a dominant system used by the majority: soybean followed by maize, sorghum or millet and, more recently (since 1998), cotton using semi-direct seeding.

In this context of very weak diversification, CIRAD-AGRONORTE-MAEDA-CODETEC research activities have resulted in recent cropping systems that enable the integration of all the DMC crops with livestock farming, have the lowest production costs and the highest gross margins. These systems should be the ones extended the most rapidly. In addition to the attractive profits and stability that they generate, they make it possible to achieve increasing independence from the very unstable regional agricultural policy. The economic performance of these cropping systems leads to the development of cropping patterns with greater stability and less economic risk. According to the level of risk chosen by the farmer, production costs can vary from \$US 300 to 600 per ha with DMC systems based on rice, soybean, maize + subsequent crops followed by cattle fattening on silage or grazing on live cover in the dry season and from \$US 500 to more than 1,300 per ha with high technology cotton growing (Séguy L. *et al.*, 2001a).

In spite of regional economic penalisation, per-hectare net margins can range from \$US 100 to more than 600 according to the choices made and the economic conditions of the year.

### III) THE IMPACTS OF DMC SYSTEMS ON SOIL ORGANIC MATTER

There is always carbon loss in land under tilled soil and monoculture (soybean, cotton), and can be estimated to be between  $-0.25$  and  $-1.40$  Mg C.ha<sup>-1</sup>.year<sup>-1</sup> over a 5-year period according to the climatic conditions. On the contrary, carbon gains can be as rapid as losses and depend on the nature





root densities for these species and combinations to a depth of 2 m (Séguy, unpublished data)) and use deep water reserves in the profile, lengthening their activity in the dry season. The very significant rise in base rates in the 0-10 cm horizon measured beneath these 'nutrients pumps' are a clear demonstration of their efficiency (Séguy *et al.*, 2001a).

Although all these species recycle bases, legumes like *Stylosanthes guyanensis* and *Arachis pintoi* strongly recycle potassium (K) and the trace elements Mn, Cu and Zn (Séguy *et al.*, 2002) when they have an important position in the rotation. According to their nature, the DMC systems therefore have selective actions on the dynamics of nutrients, as is shown by the work of Miyazawa *et al.* (2000). These results can lead to proposing to farmers decision rules for the choice and management of their DMC systems.

The best DMC systems are based on rotations that not only supply carbon at soil depth but also exert a very effective restructuring effect in the 0-20 cm horizon. After 5 years of different DMC systems the soil stability index is close to those of natural forest and savannah environments (Séguy *et al.*, 2002).

#### IV) CONCLUSIONS

Cultivated ecosystem management with DMC systems has made it possible to change a cycle of accelerated soil degradation caused by tillage techniques transferred from northern countries into a soil fertility reconstruction cycle.

The sustainable agriculture scenarios created thanks to DMC are all based on the recovery of biodiversity, using crop rotations, the integration of arable and livestock farming, the activation and diversification of soil fauna and of biological activity in general (macrofauna, microfauna and microflora). This recovery brings the evolution of cultivated systems back towards natural ecosystems and thus gives them more stability in the long term.

The economic pressure and penalisation that have led to the massive adoption of DMC systems since 1995 now enable the obtaining in this central western part of the Mato Grosso, the best productivity in Brazil for soybean, cotton and high technology rainfed rice.

Average soybean productivity is now well over 3,000 kg per ha on more than 1.3 million hectares in the region and productivity of between 4,000 and 5,500 kg per ha of rainfed rice and 3,200 to 4,500 kg/ha of seed cotton are now frequent on farms and in large areas. Little by little, the difficulties forged farmers with excellent technical profiles, able to face globalisation without subsidies.

Priority in efforts must now be applied to the dissemination of the best DMC systems combining crop and livestock farming that make it possible to produce more, with less inputs and with soils protected from climatic excesses and pesticides. For this, the training of technicians specialised in these cropping systems is becoming primordial.

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